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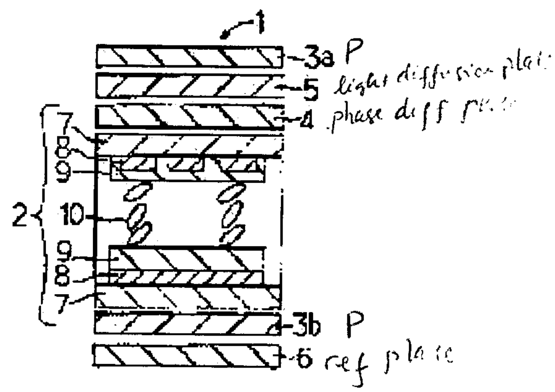
(54) REFLECTIVE-TYPE LIQUID CRYSTAL; DISPLAY DEVICE

(57)Abstract:
PROBLEM TO BE SOLVED: To provide an ECB (birefringence control) reflective-type color STN (super-twisted nematic) liquid crystal display device by which a problem that a display color is considerably changed by angles of observation is solved.
SOLUTION: A liquid crystal display device 1 consists of a liquid crystal display element 2, a polarizing plate 3a arranged on the observer side of the liquid crystal display element 2, a polarizing plate 3b arranged on the side opposite to the observer side of the liquid crystal display element 2, a phase difference plate 4 arranged between the liquid crystal display element 2 and the polarizing plate 3a, a light diffusion plate 5 arranged between the polarizing plate 3a and the phase difference plate 4, and a reflection plate 6 arranged on the outside of the polarizing plate 3b. A transparent electrode 8 and an oriented film 9 are formed on surfaces facing each other of a pair of glass substrates 7 forming the liquid crystal display element 2. Liquid crystal 10 is interposed between glass substrates 7. Thus, the ECB reflective-type color STN liquid crystal display device is constituted.



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REFLECTION TYPE LIQUID CRYSTAL DISPLAY DEVICE

[Abstract]

[Purpose] To provide an ECB type reflective color STN liquid crystal display device which prevents a display color from substantially changing according to an angle of observation.

[Means for Solving Problems] A liquid crystal display device 1 in accordance with the present invention includes a liquid crystal display element 2, a polarizing plate 3a arranged at the side of an observer with respect to the liquid crystal display element 2, a polarizing plate 3b arranged at the side opposite to the observer with respect to the liquid crystal display element 2, a phase difference plate 4 arranged between the liquid crystal display element 2 and the polarizing plate 3a, a light diffusion plate 5 arranged between the polarizing plate 3a and the phase difference plate 4, and a reflection plate 6 arranged outside the polarizing plate 3b. On each of the opposite surfaces of a pair of glass substrates 7 constituting the liquid crystal display element 2, transparent electrodes 8 and an oriented film 9 are formed. Liquid crystals 10 are disposed between the pair of glass substrates 7. An ECB type reflective color STN liquid crystal display device is constituted in this manner.

[Preferred Embodiments of the Invention] The preferred embodiments of the present invention and its comparative examples will be described with reference to FIG. 1 to FIG. 14.

[0021] (Preferred embodiments) The preferred embodiments of the present invention will be described with reference to FIG. 1 to FIG. 8. FIG. 1 is a cross-sectional view showing a liquid crystal display device in accordance with the present invention. FIG. 2 is an illustration showing a phase difference plate in accordance with the present invention. FIG. 3 is a cross-sectional view showing a light diffusion plate in accordance with the present invention. FIG. 4 is an illustration showing the arrangement conditions of members constituting the liquid crystal display device in accordance with the present invention. FIG. 5 is an illustration showing a change in a color difference in the direction of 6:00-12:00 when a coefficient Nz is changed from 0.1 to 0.5. FIG. 6 is an illustration showing a change in a color difference in the direction of 3:00-9:00 when the coefficient Nz is changed from 0.1 to 0.5. FIG. 7 is an illustration showing a change in a color difference in the direction of 6:00-12:00 when the angle which the direction of a phase lag axis forms with the direction of light diffusion is changed from 50 degrees to 80 degrees. FIG. 8 is an illustration showing a change in a color difference in the direction of 3:00-9:00 when the angle which

the direction of the phase lag axis forms with the direction of light diffusion is changed from 50 degrees to 80 degrees.

[0022] As shown in FIG. 1, a liquid crystal display device 1 in accordance with the present invention includes a liquid crystal display element 2, a polarizing plate 3a arranged at the side of an observer with respect to the liquid crystal display element 2, a polarizing plate 3b arranged at the side opposite to the observer with respect to the liquid crystal display element 2, a phase difference plate 4 arranged between the liquid crystal display element 2 and the polarizing plate 3a, a light diffusion plate 5 arranged between the polarizing plate 3a and the phase difference plate 4, and a reflection plate 6 arranged outside the polarizing plate 3b.

[0023] On each of the opposite surfaces of a pair of transparent glass substrates 7 constituting the liquid crystal display element 2, transparent electrodes 8 made of ITO (Indium Tin Oxide) are formed, and an oriented film 9 made of polyimide resin or the like is formed throughout on the surface of each of the glass substrates 7 on which the transparent electrodes 8 are formed.

[0024] The oriented film 9 is subjected to orientation treatment by rubbing so that the liquid crystal molecules of a liquid crystal 10 arranged between the pair of glass substrates 7 have a twisting structure of 250 degrees. As the liquid crystal 10, a mixed liquid crystal material is used

which is made by adding several percents cholesteric nonanoate to a nematic liquid crystal having a positive anisotropy in a dielectric constant as a chiral material for regulating the direction of twisting. The anisotropy in the refractive index Δn of the mixed liquid crystal material is 0.24, and the cell thickness of the liquid crystal element 2 is set at 7.5 μm.

[0025] As the polarizing plates 3a, 3b, a polarizing plate having a transmittance of 45 % and a degree of polarization of 99.9 % is used, and a three-dimensional phase difference plate is used as the phase difference plate 4.

[0026] The three-dimensional phase difference plate has different refractive indexes in three dimensional directions. If the main refractive indexes in the three directions are defined as nx, ny, nz, and the nx and the ny are the refractive indexes in the directions on the plane of the three-dimensional phase difference plate (nx > ny) and the nz is the refractive index in the direction of thickness of the three-dimensional phase difference plate, they satisfies a relationship of nx > ny > nz.

[0027] If the rate of the change in retardation corresponding to a change in the elevation angle of the three-dimensional phase difference plate 4 is defined as a coefficient Nz expressed by the following formula, with the use of three dimensional refractive indexes, Nz = (nx-nz)/(nx-ny), when a wavelength λ is 633 nm, it is preferable that Nz = 0.2 to 0.4,

and in the present preferred embodiment, Nz = 0.3. Also, the three-dimensional phase difference plate 4 made of polycarbonate and having a retardation value of 2000 nm is used in the present preferred embodiment.

[0028] The phase difference plate 4 used in the present preferred embodiment, as shown in FIG. 2, has a constitution in which five phase films 11, each of which has a coefficient Nz of 0.3 and a retardation value of 400 nm, are laminated with their phase lag axes 12 aligned.

[0029] The light diffusion plate 5, as shown in FIG. 3, is made by laminating two films 14a, 14b, each of which has two kinds of regions 13a, 13b which are different from each other by about 0.04 in refractive index and are arranged alternately at a predetermined angle θ (the angle θ can be set at an arbitrary value, and preferably be set at a value between 30 degrees to 50 degrees, and is set at 45 degrees in the present preferred embodiment). For example, a lumistay manufactured by Sumitomo Chemical Co. or the like can be used as the light diffusion plate 5.

[0030] Light 15 vertically entering the light diffusion plate 5 emits as it is, and light 16 entering the light diffusion plate 5 in parallel to the angle θ diffuses owing to Bragg diffraction and can improve a change in the elevation angle of a display color. However, owing to the constitution of the films 14a, 14b, the light 16 entering the light diffusion

plate 5 in parallel to the angle θ is diffused only in one direction and hence can improve a change in the elevation angle of the display color only in one direction.

[0031] Accordingly, in the present preferred embodiment, the films 14a, 14b are laminated such that they are opposed to each other in the angle θ with respect to a normal, to improve a change in the elevation angle of the display color in two directions of 3:00-9:00.

[0032] The light diffusion plate 5 used in the present preferred embodiment has no phase difference and is placed between the polarizing plate 3a and the phase difference plate 4 for protecting itself.

[0033] Next, the arrangement conditions of members constituting the liquid crystal display device 1 will be described. As shown in FIG. 4, an orientation axis (rubbing axis) of the liquid crystal molecules of one oriented film 9 is inclined clockwise by an angle of 35 degrees from the direction of 9:00, as shown by an arrow A. An orientation axis (rubbing axis) of the liquid crystal molecules of the other oriented film 9 is inclined clockwise by an angle of 55 degrees from the direction of 12:00, as shown by an arrow B. Therefore, the twisting angle of the liquid crystal molecule is set at 250 degrees.

[0034] The light is diffused in two directions of 3:00-9:00 by the light diffusion plate 5, as shown by an arrow C. The

direction of absorption axis of the polarizing plate 3a is inclined clockwise by an angle of 70 degrees from the direction of 12:00, as shown by an arrow D. The direction of absorption axis of the polarizing plate 3b is inclined clockwise by an angle of 5 degrees from the direction of 6:00, as shown by an arrow E. The direction of the phase lag axis 12 of the phase difference plate 4 is inclined clockwise by an angle of 30 degrees from the direction of 6:00, as shown by an arrow F.

[0035] In order to improve a change in the elevation angle of the display color in all directions in good balance, it is preferable that the angle between the direction of the phase lag axis 12 of the phase difference plate 4 and the direction of light diffusion of the light diffusion plate 5, that is, the angle which the arrow C forms with the arrow F is set at 55 to 75 degrees. In the present preferred embodiment, the angle which the arrow C forms with the arrow F is set at 60 degrees.

[0036] Here, the reason why the coefficient Nz of the phase difference plate 4 is preferably 0.2 to 0.4 will be described.

[0037][formula 1]

$$\Delta E^{*}ab$$

[0038] The above-described formula designates a color difference in accordance with JIS Z 8729, and as this value increases, a change in the color difference increases and

visual field characteristics deteriorate.

[0039] As shown in FIG. 5, if the coefficient Nz is changed from 0.1 to 0.5, a change in the color difference in the direction of 6:00-9:00 becomes large and the visual field characteristics deteriorate at Nz = 0.1 and Nz = 0.5.

[0040] Further, as shown in FIG. 6, if the coefficient Nz is changed from 0.1 to 0.5, a change in the color difference in the direction of 3:00-9:00 becomes large and the visual field characteristics deteriorate at Nz = 0.1 and Nz = 0.5.

[0041] Therefore, at the coefficient Nz of 0.2 to 0.4, a change in the elevation angle of the display color can be improved in good balance in all directions.

[0042] Further, the reason why the angle between the direction of the phase lag axis 12 of the phase difference plate 4 and the direction of the light diffusion plate 5 is preferably set at 55 degrees to 75 degrees will be described.

[0043] As shown in FIG. 7, if the angle between the direction of the phase lag axis 12 of the phase difference plate 4 and the direction of the light diffusion plate 5 is changed from 50 degrees to 80 degrees, a change in the color difference in the direction of 6:00-12:00 does not change much.

[0044] However, as shown in FIG. 6, if the angle between the direction of the phase lag axis 12 of the phase difference plate 4 and the direction of the light diffusion plate 5 is changed from 50 degrees to 80 degrees, when the angle between

the direction of the phase lag axis 12 of the phase difference plate 4 and the direction of the light diffusion plate 5 is 50 degrees and 80 degrees, a change in the color difference in the direction of 3:00-9:00 becomes large and the visual field characteristics deteriorate.

[0045] Therefore, if the angle between the direction of the phase lag axis 12 of the phase difference plate 4 and the direction of the light diffusion plate 5 is set at 55 degrees to 75 degrees, a change in the elevation angle of the display color can be improved in good balance in all directions.

[0046] (Comparative example) A comparative example will be described with reference to FIG. 9 and FIG. 10. FIG. 9 is a cross-sectional view showing a conventional liquid crystal display device. FIG. 10 is an illustration showing the arrangement conditions of members constituting the conventional liquid crystal display device.

[0047] As shown in FIG. 9, the conventional liquid crystal display device 51 includes a liquid crystal display element 2, a polarizing plate 3a arranged at the side of an observer with respect to the liquid crystal display element 2, a polarizing plate 3b arranged at the side opposite to the observer with respect to the liquid crystal display element 2, a phase difference plate 52 arranged between the liquid crystal display element 2 and the polarizing plate 3a, and a reflection plate 6 arranged outside the polarizing plate 3b.

[0048] The liquid crystal display element 2 is the same as the liquid crystal display element 2 used in the present preferred embodiment in accordance with the present invention. That is, on each of the opposite surfaces of a pair of transparent glass substrates 7, transparent electrodes 8 made of ITO (Indium Tin Oxide) are formed, and an oriented film 9 made of polyimide resin or the like is formed throughout on the surface of each of the glass substrates 7 on which the transparent electrodes 8 are formed.

[0049] The oriented film 9 is subjected to orientation treatment by rubbing so that the liquid crystal molecule of a liquid crystal 10 arranged between the pair of glass substrates 7 has a twisting structure of 250 degrees. As the liquid crystal 10, a mixed liquid crystal material is used which is made by adding several percents cholesteric nonanoate to nematic liquid crystal having a positive anisotropy in a dielectric constant as a chiral material for regulating the direction of twisting. The Δn of the mixed liquid crystal material is 0.24, and the cell thickness of the liquid crystal element 2 is set at 7.5 μm. $\Delta n \times d = 0.24 \times 7500 = 1800$ nm

= 7500nm

[0050] As the polarizing plates 3a, 3b, a polarizing plate having a transmittance of 45 % and a degree of polarization of 99.9 % is used, and a two-dimensional phase difference plate is used as the phase difference plate 52. The two-dimensional phase difference plate 52 is made of polycarbonate and has a

retardation value of 2000 nm.

[0051] Next, the arrangement conditions of members constituting the liquid crystal display device 51 will be described. As shown in FIG. 10, an orientation axis of the liquid crystal molecules of one oriented film 9 is inclined clockwise by an angle of 35 degrees from the direction of 9:00, as shown by an arrow G. The orientation axis (rubbing axis) of the liquid crystal molecules of the other oriented film 9 is inclined clockwise by an angle of 55 degrees from the direction of 12:00, as shown by an arrow H. Therefore, the twisting angle of the liquid crystal molecule is set at 250 degrees.

[0052] The direction of absorption axis of the polarizing plate 3a is inclined clockwise by an angle of 5 degrees from the direction of 6:00, as shown by an arrow I. The direction of absorption axis of the polarizing plate 3b is inclined clockwise by an angle of 70 degrees from the direction of 12:00, as shown by an arrow J. The direction of the phase lag axis of the phase difference plate 52 ~~is~~ inclined clockwise by an angle of 30 degrees from the direction of 6:00, as shown by an arrow K.

[0053] Here, the visual field characteristics of the liquid crystal display device 1 in accordance with the present invention described in the preferred embodiment will be compared with the visual field characteristics of the

conventional liquid crystal display device 51 described in the comparative example with reference to FIG. 11 and FIG. 12. FIG. 11 is an illustration showing a change in the color difference in the direction of 6:00-12:00 of the conventional liquid crystal display device 51, that of the liquid crystal display device 1 in accordance with the present invention, and that of the liquid crystal display device 1 in accordance with the present invention from which the light diffusion plate 5 is removed. FIG. 12 is an illustration showing a change in the color difference in the direction of 3:00-9:00 of the conventional liquid crystal display device 51, that of the liquid crystal display device 1 in accordance with the present invention, and that of the liquid crystal display device 1 in accordance with the present invention from which the light diffusion plate 5 is removed. In this respect, in FIG. 11 and FIG. 12, with or without in the notation designates with or without the light diffusion plate 5.

[0054] As shown in FIG. 11, a change in the color difference in the direction of 6:00-12:00 of the liquid crystal display device 1 in accordance with the present invention and that of the liquid crystal display device 1 in accordance with the present invention from which the light diffusion plate 5 is removed do not much change, and both of them show good characteristics, but that of the conventional liquid crystal display device 51 becomes extremely large.

[0055] For example, a case where a change in the elevation angle of the display color is produced when the color difference is expressed by the following formula will be described.

[0056][formula 2]

$$\Delta E^{*}ab = 6$$

[0057] The range in which a change of the elevation angle of the display color is not produced in the direction of 6:00-12:00 is about 10 degrees for the conventional liquid crystal display device 51, and is about 80 degrees for the liquid crystal display device 1 in accordance with the present invention and for the liquid crystal display device 1 in accordance with the present invention from which the light diffusion plate 5 is removed.

[0058] Further, as shown in FIG. 12, a change of the elevation angle of the display color in the direction of 3:00-9:00 shows good visual field characteristics for the liquid crystal display device 1 in accordance with the present invention, but becomes large for the liquid crystal display device 1 in accordance with the present invention from which the light diffusion plate 5 is removed and for the conventional liquid crystal display device 51.

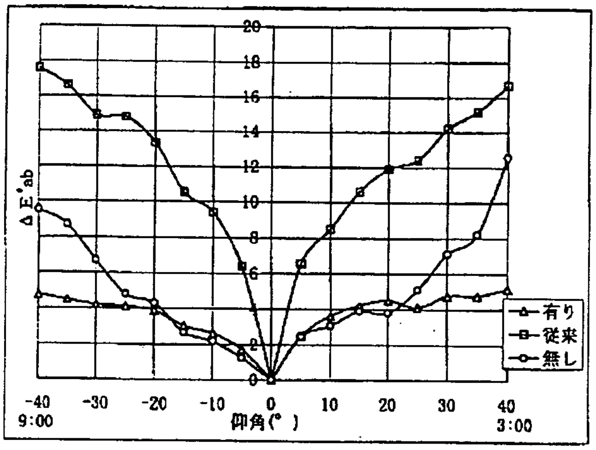
[0059] For example, a case where a change in the elevation angle of the display color is produced when the color difference is expressed by the following formula will be

described.

[0060][formula 3] $\Delta E^{*}ab = 6$

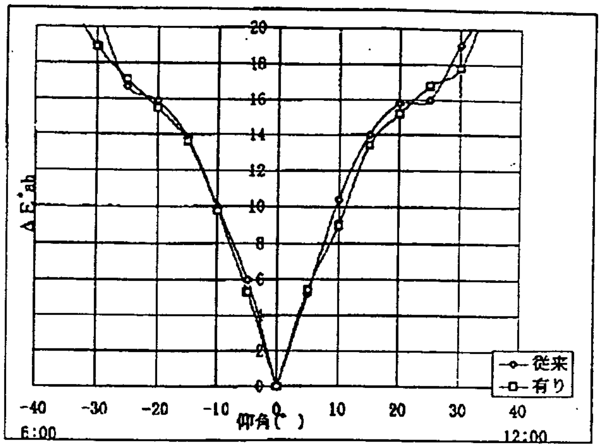
[0061] The range in which a change in the elevation angle of the display color is not produced in the direction of 3:00-9:00 is about 9 degrees for the conventional liquid crystal display device 51, and is about 55 degrees for the liquid crystal display device 1 in accordance with the present invention from which the light diffusion plate 5 is removed, and is not less than 80 degrees for the liquid crystal display device 1 in accordance with the present invention.

【図１２】



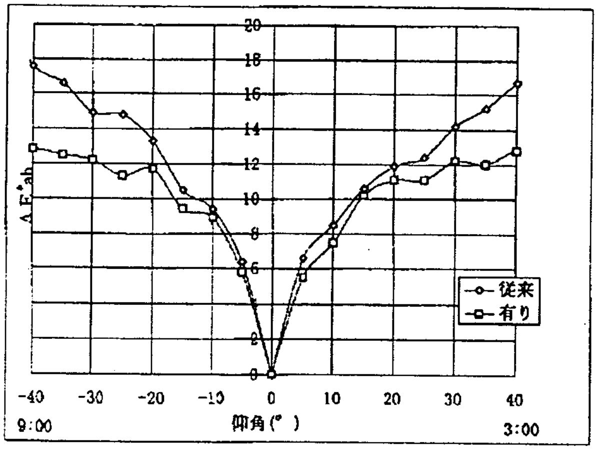
ΔE*ab
-40
-30
-20
-10
0
10
20
30
40
9:00
3:00
仰角(°)
有り
従来
無し

【図１３】



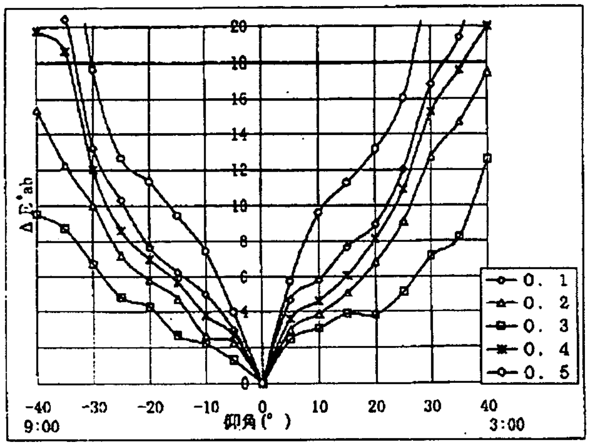
ΔE*ab
-40
-30
-20
-10
0
10
20
30
40
6:00
12:00
仰角(°)
従来
有り

【図１４】

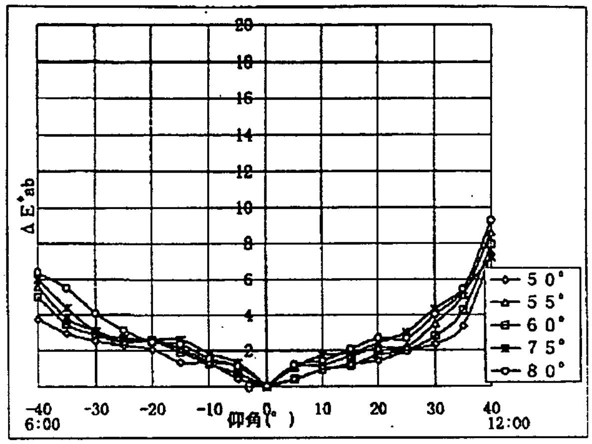


ΔE*ab
-40
-30
-20
-10
0
10
20
30
40
9:00
3:00
仰角(°)
従来
有り

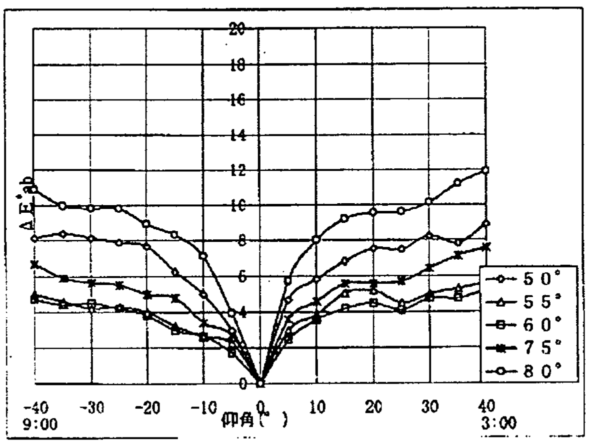
【図6】



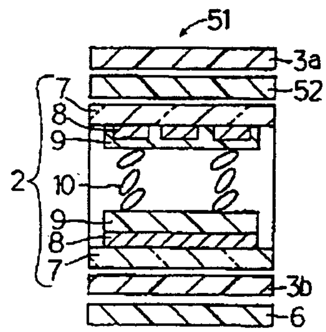
【図7】



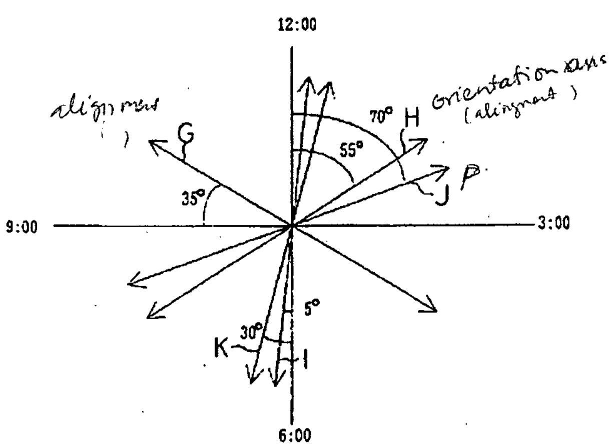
【図8】



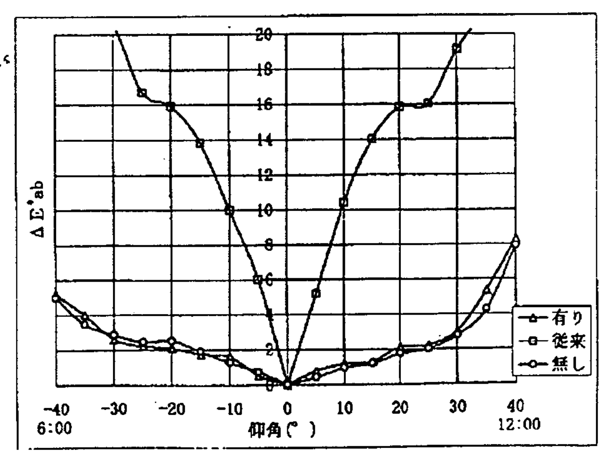
【図9】



【図10】



【図11】



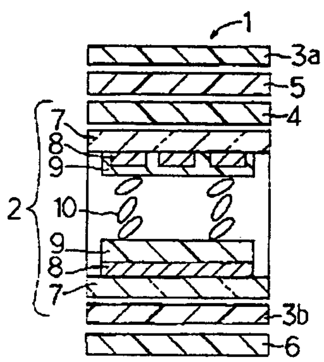
【図１３】従来の液晶表示装置及び従来の液晶表示装置に光拡散板を設けた液晶表示装置の６：００－１２：００方向の色差変化を示す説明図である。

【図１４】従来の液晶表示装置及び従来の液晶表示装置に光拡散板を設けた液晶表示装置の３：００－９：００方向の色差変化を示す説明図である。

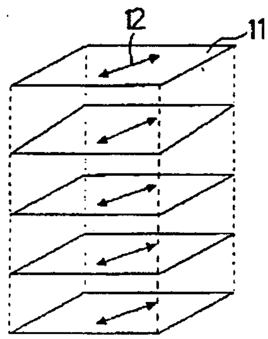
【符号の説明】

１　液晶表示装置
２　液晶表示素子
３ａ、３ｂ　偏光板
４　位相差板
５　光拡散板
６　反射板
７　ガラス基板
８　透明電極
９　配向膜
１０　液晶
１１　位相差フィルム
１２　遅相軸
１３ａ、１３ｂ　領域
１４ａ、１４ｂ　フィルム
１５　垂直に入射した光
１６　角度θと平行に入射した光
５１　液晶表示装置
５２　位相差板

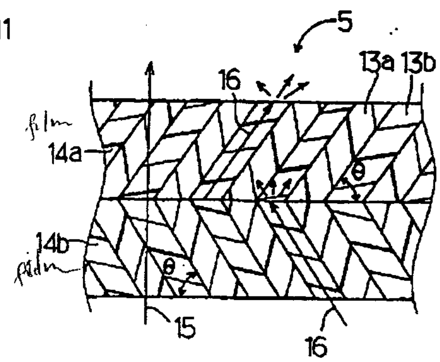
【図１】



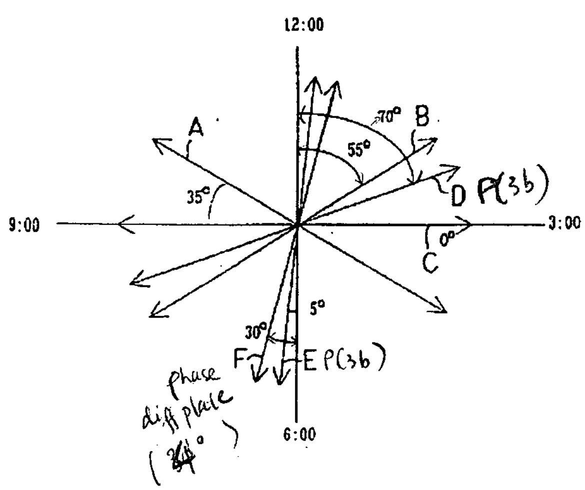
【図２】 phase diff plate



【図３】 light diffusion



【図４】



【図５】